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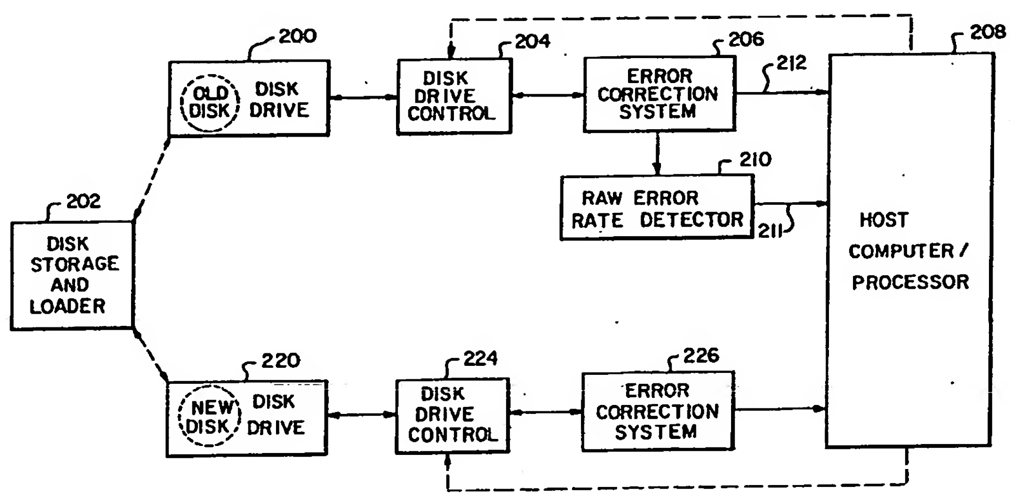

(57) Abstract

An optical disk system for long term storage which periodically retrieves an optical disk storing valuable data and measures its raw error rate. The raw error rates thus periodically sampled are extrapolated to determine the time when the disk raw error rate will reach a predetermined error rate threshold level. If this time is prior to the next scheduled (periodic) measurement of the raw error rate, then all the data is read from the disk, processed by an error correction system (to fully recover the stored data), and written onto a new disk. Preferably, the predetermined error rate threshold level is considerably less than the highest raw error rate of which the error correction system is capable of correcting. Thus, the optical disk degradation monitoring system automatically avoids loss of data due to degradation of the optical disk over time.

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MONITORING OPTICAL DISK LONG TERM ERROR RATES

TECHNICAL FIELD OF THE INVENTION

The field of the invention relates to optical disk usage including drives and the manner in which the drives and the overall system are used. It also relates to the fields of long-term data reliability, and integrity.

BACKGROUND OF THE INVENTION

Optical disks are used to store digital data in large amounts. The method in which the data is stored on writable optical disks involves burning small holes (or causing some other physical change) in the optical disk using an intense laser beam and then reading the disk with a lower intensity beam. In some cases the holes may not be perfectly formed and therefore error correction is required. Error correction techniques typically add redundant data to the user data prior to recording on the disk and then, in playing back the recorded data (including the redundant data), any errors are located and corrected. This technique insures that data can be reliably recovered from an optical disk even though some degradation may have occurred in the actual information stored on the disk, as long as the percentage of erroneous data ("error rate") does not exceed the correction capability of the error correction system.

At this time, the archival capabilities of optical disks are a source of uncertainty. When many thousands, if not millions, of pages of data are stored on the optical disk, an ability to recover this data (often many years later) is absolutely essential because of the very high value

of the data stored. However, if for any reason the errors accumulate on the optical disk to the point where error recovery cannot occur (i.e., the error rate exceeds the capability of the error correction system), then the data would be lost. Many techniques are known to correct for the recovery of optical disk data and standards have been developed primarily around the Reed-Solomon technique.

Specific examples of patents covering the Reed-Solomon and similar data activities include U.S. Patent No. 4,567,594 entitled "Reed-Solomon Error Detection and Error Correction System Employing Pipeline Processes"; U.S. Patent No. 4,604,748 entitled "Data Correction System With Error Correction".

DESCRIPTION OF THE PROBLEM TO BE SOLVED

The long-term readability of optical disks remains an area of uncertainty because of the difficulty of anticipating long term degradations which may occur within the optical disks. Most optical disks already use automatic error detection and correction technology which can generally handle error rates which may be as much as 10 or 1000 times greater than that found in the data on the disk when it was originally written onto the disk. The error rate in data directly read off the disk is termed raw error rate. The corrected error rate is the error rate after the error correction has been performed. A typical error correction system employs overlaid Reed-Solomon codes. The maximum error rate of which the error correction system is capable of handling is termed the average recoverable error rate. Obviously, the data on a disk cannot be read back, using conventional means, when the raw error rate exceeds the average

recoverable error rate.

SUMMARY OF THE INVENTION

However, in accordance with the invention, the onset of this condition is anticipated by monitoring the error rate of the disk at a frequency of (for example) once per month. Dedicated monitoring data may be written on the disk at various locations, the monitoring data having been designed specifically for the purpose of easily detecting the raw error rate. The raw error rate in these locations may be monitored periodically to project when the raw error rate condition will be so high as to render the error correction system ineffective. Alternatively, the raw error rate of actual data stored on the disk may be monitored in certain locations or across the entire disk. Once the raw error rate reaches (for example) one-fifth of the correction error rate, a back-up disk is automatically made and the original disk discarded. Significantly, the data recorded on the back-up disk is obtained by performing error correction upon the raw data from the original disk.

DESCRIPTION OF THE DRAWINGS

The invention is now described in detail with reference to the accompanying drawings, of which:

Fig. 1 is a graph illustrating the concept and operation of the invention;

Fig. 2 is a block diagram illustrating a system embodying the invention; and

Fig. 3 illustrates the location of monitoring data on an optical disk.

DETAILED DESCRIPTION

Fig. 1 shows, diagrammatically, the reciprocal of the raw error rate on an optical disk

as a function of time. The error rate may degrade due to degradation of the disk in some manner. At the time shown as point 101 in Fig. 1, the raw error rate resides at level 102. Later, the error rate at time 104 has increased to level 106 so that a trend of error rates can be extrapolated as shown by curve 107 to predict that the raw error rate will reach a predetermined rewrite error rate level 108 at time 110. The rewrite error rate level 108 is chosen to be considerably in excess of the average recoverable error rate 109. Thus, before time 110, the data on the disk is read, corrected by the error correction system and rewritten onto a new optical disk. As a result, the new disk has an error rate which is well below the correction error rate.

Typically, this time or duration would occur over a number of months, if not years.

The basic technique therefore is to store the data on an optical disk, and then periodically note the raw error rate. Sometime, for example a week or a month later, the disk is scanned again and the raw error rate of selected areas is compared to the original raw error rate at the time the disk was written. This raw error rate data is extrapolated to predict how long the disk will continue to be within the "safe" rewrite error rate at level 108 (Fig. 1). The extrapolation process may occur as follows. The raw error rate of the "old" optical disk is periodically measured (checked) and stored in non-volatile memory, such as disk storage associated with the host computer 208 or the "old" optical disk itself. Two such measurements are points 102 and 106 in Fig. 1, corresponding to the raw error rates measured at periodic check times 101 and 104. At check time 104, when the raw error rate

106 has been measured and stored, the host computer 208 extrapolates the two measurement points 102, 106 to predict the raw error rate 103 for the next check time 105. As long as the predicted (extrapolated) raw error rate 103 does not exceed the rewrite error rate 108 of Fig. 1, no action is taken at time 105. On the other hand, if the predicted raw error rate exceeds the rewrite error rate 108, the "old" disk is discarded and its contents corrected and rewritten onto a new disk. In this case, the disk data is copied, error-corrected and rewritten onto a new disk. As long as the raw error rate is predicted (via extrapolation) to not exceed the rewrite error rate 108 before the next scheduled check, then no action is taken before the next scheduled check. Sometime later again, the raw error rate of the disk is checked in selected areas and again an assessment is made of the predicted raw error rate. This process occurs repeatedly until the disk is no longer required or until the disk is discarded because it was predicted to reach the safe error rate 108 before the next check.

The selection of specific areas on the disk where error rate checks could occur include, for example, three bands on the disk, an outer band, a center band, and an inner band. Depending on the required accuracy of the raw error rate measurement, the size of the band would be a few tracks or many tracks. Alternatively, the error estimation would be performed at numerous equally spaced tracks across the disk (depending upon the anticipated characteristics of the degradation).

Referring to Fig. 2, a disk drive 200 receives a selected optical disk from an optical disk storage and loader 202 under control of disk

control electronics 204. Selected raw data read from the selected disk is processed by an error correction system 206. A raw error measurement unit 210 measures the raw error rate of the selected raw data in cooperation with the error correction system 206, and furnishes the raw error rate to the host computer 208 via lines 211. Preferably, the selected raw data comprises monitoring data which has been predetermined for ease of raw error rate computation and written into predetermined locations on the disk.

In accordance with the operation illustrated in Fig. 1, the host computer may direct the loader 202 to periodically load a given disk (presumably storing valuable data) into the disk drive 200 in order to sense the disk's current raw error rate at the detector 210. All the data on the disk is read out through the error correction system 206 into the host computer 208 for correction and eventual rewriting onto a new disk whenever any one of the following occurs: (a) The raw error rate is found to exceed the rewrite error rate; or (b) The host processor 208 computes via the extrapolation process described previously herein that the raw error rate will exceed the rewrite error rate at the time of the next scheduled check of the raw error rate. The resulting error-corrected data is ready to be recorded onto a new optical disk. A "new" disk is loaded into another disk drive 220 and the copying of the error-corrected data (originally obtained from from the "old" disk in the drive 200) to the "new" disk in the drive 220 under supervision of the processor 208 now begins. The data thus passes from the "old" disk in the disk drive 200 through the disk controller 204 to the error

corrector 206 and to the processor 208 via line 212. The processor 208 then passes the data to an error corrector 226 which casts (encodes) the data into correctable form for writing onto the new disk 220. The data thus encoded is written on the "new" disk in the drive 220 under control of the controller 224.

Example

As one example, the error correction system 206 is a Reed-Solomon error correction encoding/decoding system having the capability of correcting as many as (for example) 10^{-3} erroneous bits for every bit on the data stream. Thus, its average recoverable error rate is 10^{-3} errors per bit. In other words, the error correction system 206 can produce error free data from encoded data as long as the encoded data has no more than one incorrect bit for every 10^{-3} bits read out from the disk 200. Preferably, in this example, the rewrite error rate (level 108 in Fig. 1) is chosen to be one order of magnitude (one factor of ten) below the average recoverable error rate, or 10^{-4}.

The error rate monitoring data may be written on an optical disk 300 in three designated tracks 301, 303, 305 as shown in Fig. 3.

While the detector 210 has been described as responding to special monitoring data to sense the disk's raw error rate, the monitoring data may be dispensed with, and the detector 210 may instead infer a disk raw error rate by simply observing operation of the error correction system 206 as user data from the disk (or from specified locations thereon) is read out and processed by the error correction system 206. The detector 210 may simply count the number of error locations identified in a

given amount of data by the error correction system 206.

While the invention has been described as using two disk drives to effect the copying of the recovery data onto the new disk, it may be readily implemented using a single disk drive by simply storing the recovered data in a sufficiently large memory while the old disk is removed from the disk drive and the new disk is loaded into the disk drive.

Accordingly, while the invention has been described in detail with specific reference to preferred embodiments thereof, variations and modifications thereof may be made without departing from the spirit and scope of the invention.

CLAIMS:

1. An optical disk degradation monitoring system, comprising:

an error correction system characterized by an average recoverable error rate and including means for encoding user data in accordance with an error correction code and for decoding data thus encoded;

a disk drive including means for receiving encoded data from said error correction system and recording it on a disk and for reading data from a disk and sending it to said error correction system for decoding;

means for periodically sensing the raw error rate of data stored on said disk, and, whenever necessary to avoid said raw error rate from exceeding said average recoverable error rate, reading the data from said disk to said error correction system to generate corrected data therefrom and causing said error corrected data to be recorded on another disk.

2. In a disk drive including means for loading and unloading disks for reading or writing of data therein and error corrector means for encoding data to be written and decoding data read from said disk characterized by an average recoverable error rate, the improvement comprising:

sensing means for periodically measuring the raw error rate of data previously stored on a disk in said disk drive; and

means responsive to said sensing means for recovering through said error corrector means the data recorded on said disk and transferring it to another disk whenever said raw error rate approaches said average recoverable error rate.

3. The disk drive of claim 2 wherein said means for recovering is operable whenever it observes a trend of previous measurements of raw error rates on said disk by said sensing means indicating that the raw error rate of said disk will exceed a predetermined threshold upon the next raw error rate measurement performed by said sensing means, wherein said predetermined threshold is no greater than said average recoverable error rate.

4. In a disk drive having access to a plurality of disks, the improvement comprising means for periodically sensing the raw error rate of data previously stored on a given one of said disks and means responsive thereto whenever said raw error rate closely approaches a threshold for causing said stored data to be read from said disk and to cause it to be error-corrected and thereafter recorded on another one of said disks.

5. In a disk drive, the improvement comprising means for periodically sensing the raw error rate of data previously stored on a disk in said disk drive and means responsive thereto whenever said raw error rate closely approaches a threshold for causing said stored data to be read from said disk and to cause it to be error-corrected and thereafter recorded on another disk.

6. The disk drive of claim 4 or 5 further comprising an error correction system by which said means for causing causes said data to be error-corrected, said error correction system being characterized by a maximum correctable error rate, said threshold being no greater than said maximum correctable error rate so that said raw error rate never exceeds said maximum correctable error rate.

7. In a disk drive adapted to read and

write data in one of a plurality of optical disks to which it has access, said disk drive including an error correction system characterized by a maximum correctable error rate, said error correction system being adapted to encode user data prior to writing on said disk and decode data read from said disk, the improvement comprising:

means for causing the raw error rate of data previously recorded on one of said optical disks to be measured periodically;

means for predicting from said previous measurements of said raw error rate whether said raw error rate will exceed a predetermined threshold before the next measurement of said raw error rate of said data on said disk, and, if so, causing said data to be read from said disk, processed by said error correction system and rewritten onto unused space in the same disk or onto another disk.

8. The disk drive of claim 7 wherein said means for predicting stores the raw error rates previously measured from data stored on said disk and extrapolates them to determine when said raw error rate will exceed said threshold.

9. The disk drive of claim 7 wherein said means for causing the raw error rate to be measured causes the number of error locations in predetermined portions of said data previously recorded on said disk to be counted.

10. The disk drive of claim 9 wherein said predetermined portions include pre-defined data patterns in predetermined locations on said disk.

11. The disk drive of claim 9 wherein said predetermined portions comprise predetermined locations on said disk storing user data.

12. The disk drive of claim 10 where said

predetermined locations comprise a peripheral track, an interior track and an intermediate track on said disk.

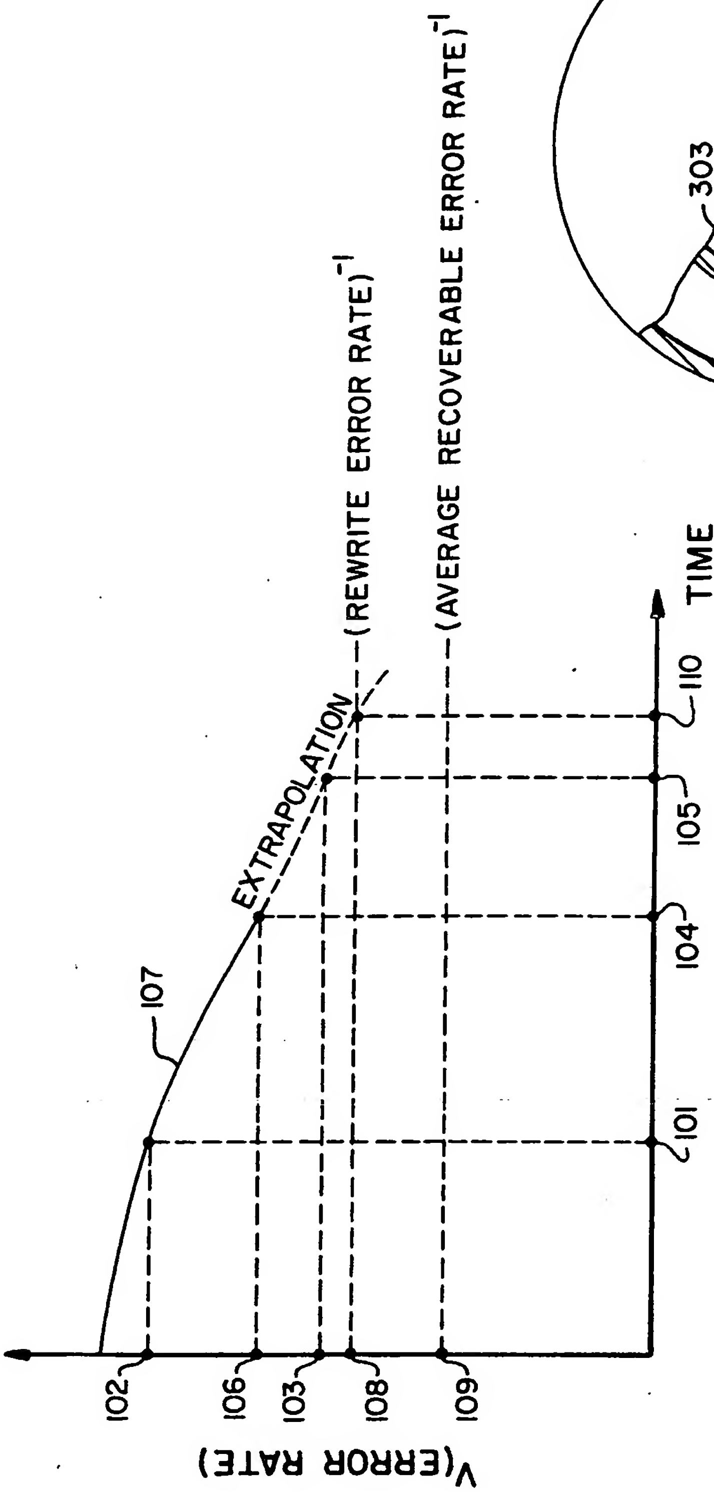
13. The disk drive of claim 11 where said predetermined locations comprise a peripheral track, an interior track and an intermediate track on said disk.

14. The system of claim 1 further comprising:

means for storing a plurality of disks and for loading a selected one of said disks into said disk drive and for removing it therefrom.

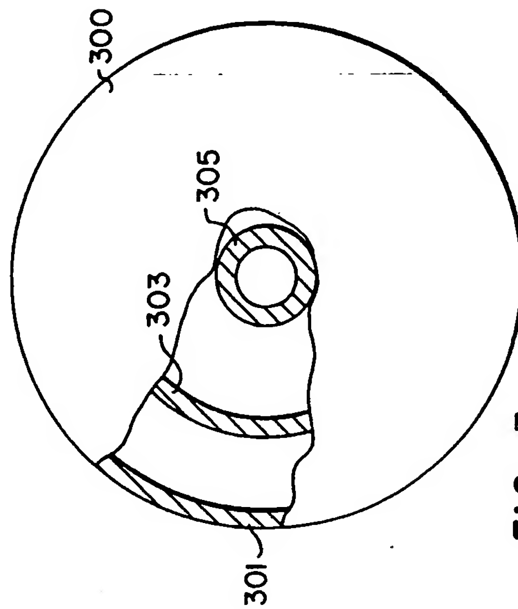
15. The system of claim 14 further comprising:

means for periodically selecting one of a plurality of said disks and causing said loading means to load said selected disk into said disk drive so that said means for sensing the raw error rate may thereafter sense the raw error rate of data stored on said disk.



(REWRITE ERROR RATE)$^{-1}$
(AVERAGE RECOVERABLE ERROR RATE)$^{-1}$
EXTRAPOLATION
TIME
V(ERROR RATE)
107
101
104
105
110
102
106
103
108
109

FIG. 1



300
305
303
301

FIG. 3

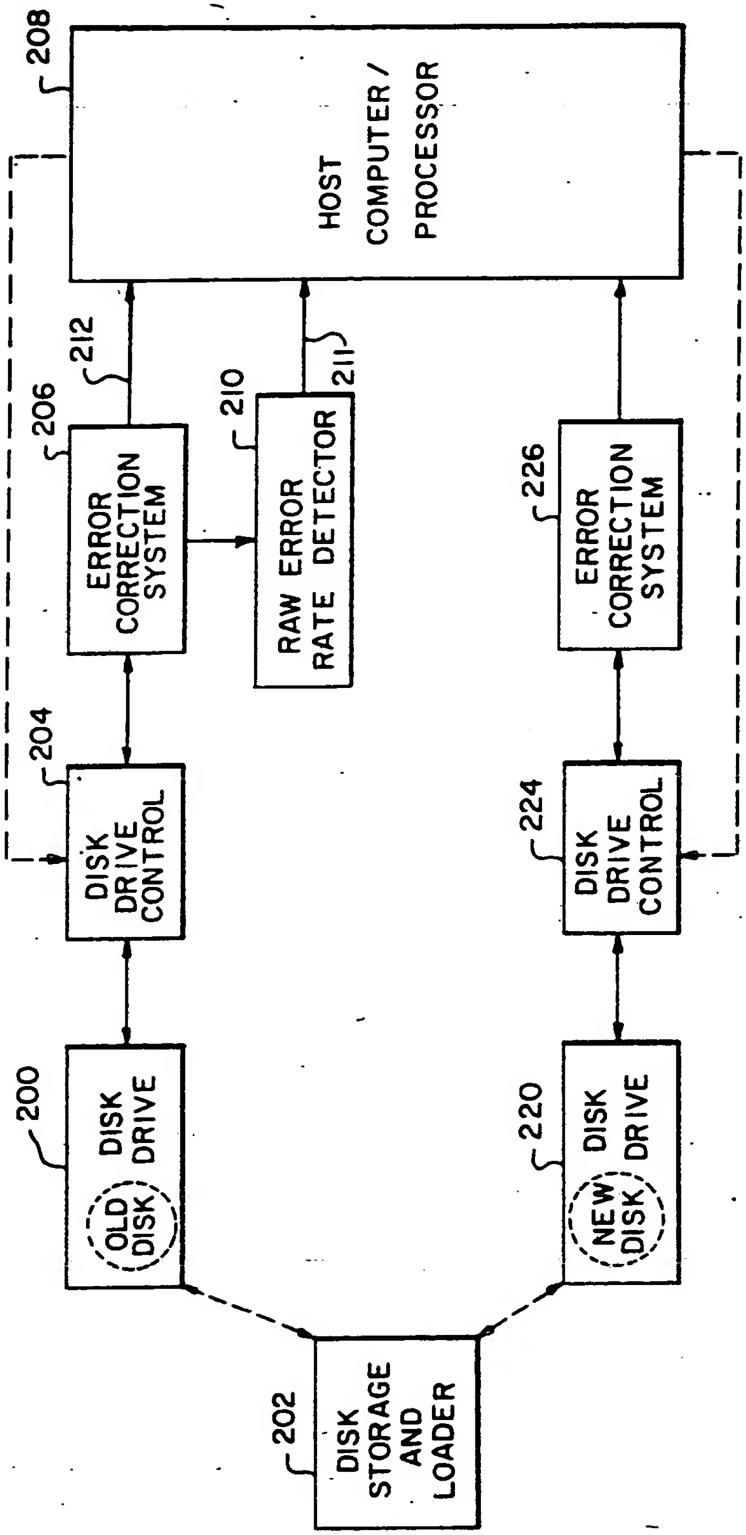

208
HOST COMPUTER / PROCESSOR
212
211
206
ERROR CORRECTION SYSTEM
210
RAW ERROR RATE DETECTOR
204
DISK DRIVE CONTROL
200
OLD DISK
DISK DRIVE
202
DISK STORAGE AND LOADER
226
ERROR CORRECTION SYSTEM
224
DISK DRIVE CONTROL
220
NEW DISK
DISK DRIVE

FIG. 2

INTERNATIONAL SEARCH REPORT

International Application No PCT/US / 88/ 04608

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 4 G11B27/36 ; G11B20/18

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 4	G11B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
X	PATENT ABSTRACTS OF JAPAN vol. 10, no. 110 (P-450) 2167 24 April 1986, & JP-A-60 239927 (RICOH K.K.) 28 November 1985, * see the whole document * ---	1-15
X	PATENT ABSTRACTS OF JAPAN vol. 10, no. 264 (P-495) 2320 09 September 1986, & JP-A-61 87271 (CANON INC) 02 May 1986, * see the whole document * ---	1-15
P,X	PATENT ABSTRACTS OF JAPAN vol. 12, no. 415 (P-781) 3262 04 November 1988, & JP-A-63 152063 (MATSUSHITA ELECTRIC IND CO LTD) 24 June 1988, * see the whole document * ---	1-15

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
17 MAY 1989	-5 JUN 1989
International Searching Authority	Signature of Authorized Officer

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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
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A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 19 (P-537) 2466 20 January 1987, & JP-A-61 192076 (NEC CORP) 26 August 1986, * see the whole document * ---	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US-A- 4794467	27-12-88
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